Alternative Packaging Study

Final Out Brief

February 9, 2009

Final Outbrief Agenda

- Introduction: Alternative Packaging Study Overview
- Interim Review Summary
- Topic Explored since Interim Review
- Conclusions
- Take-away Messages

Introduction

- NASA solicited a study to identify means to reduce overhead in mass and volume for exploration packaging
- OSS proposed a broad-reaching study of how packaging can be optimized to most effectively support the Constellation mission
- GOAL: Identify high-leverage recommendations for packaging which will have sustained value when embedded in the Cx architecture
- Sustainability was identified by NASA as a principal concern
  - Program sustainability: To what extent can effective packaging solutions contribute to the stability and growth of the Constellation program
  - Technical sustainability: To what extent can effective packaging simplify and streamline operations, improve mass and volumetric efficiency, and promote successful exploration using a technically and operationally sustainable architecture

Summary of Interim Review

- Proportions
  - LIDS hatch was proposed as a “go/no-go” constraint, but its validity was questioned
  - The validity of a parametric proportional scheme for packaging was not disputed
- Barrier-free environment
  - Ability for packages to transit the architecture was discussed with reference to ISS Airlock example
- Lifecycle Analysis
  - Discussion led to greater emphasis during final study phase, specifically in the area of optimizing performance and determining metrics by mission phase
- Food and Waste Packaging
  - Dry food and water recovery identified as key enablers to low packaging overhead
  - Food bags recycled for waste containment
- Metrics
  - The applicability of metrics has been recognized as a mission-phase sensitive issue
  - Designing with this in mind will reduce mass, volume, and related costs
- Analogs
  - Examples were too “emergency-related”
  - OSS was encouraged to explore more additional, more relevant analogs

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Summary of Interim Review (cont.)

- ECLSS consumables packaged as high energy fluids
  - OSS recommended approach was included in Boeing MFHE ECLSS trades, but lost to a less efficient alternative
- Lunar Sample Return Packaging
  - OSS showed one initial concept, with another concept in process at time of review
  - We have since explored a more efficient concepts
- Architectural Simulations
  - OSS discussed the potential value of applying simulations within which packaging variations could be operationally assessed
  - It has since become apparent that the Cx Architecture team and others are already using prototypes to support operational simulations
  - Subsequent packaging concepts may be appropriate for inclusion in these activities

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Topics Explored Since Interim Review

- Terrestrial Analogs: Emphasis on Low-mass/volume examples
- Edible Packaging Materials
- 1/6 G as a Contributor to Efficient Packaging
- Polyethylene Packaging for Exploration
- Modular Stowage Enclosure Concepts
- Sample Return Packaging (revisited)
- Stowage Curtain Concepts
- Comparison of Cx vs. STS/ISS packaging
- Lifecycle Implications for Efficient Packaging

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Terrestrial Analogs

- Observations revealed through analog research
  - Packaging technology has advanced since Apollo
  - The weighting of metrics influences the optimal manifestation of packaging for any application
  - Versatility minimizes overhead
  - "Substance over Style" : avoid artificially imposed paradigms
  - Fabric solutions are highly effective in mass/volume critical applications
  - Optimal dispersal of packaging is critical on performance sensitive vehicles
  - Carefully assess mission and lifecycle to identify optimization opportunities
  - Use the lightest weight material capable of enduring its limited mission
  - Generic packaging is wasteful as compared to optimized point designs
  - Generic accommodations for packaging are favorable
  - Innovative operational solutions may eliminate packaging altogether

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Observations revealed through analog research (cont.)

- ISS/STS Crew Transfer Bags or variations on this concept are entirely unsuited for exploration
  - Artificially imposed proportions
  - 0-g operational
  - Reusable after return to Earth
- Packaging must endure and protect contents, then either “disappear” or provide additional value as a resource
  - Provide mission phase-specific performance and endurance
  - Use materials offering supplemental value
- Providing stowage accommodations in addition to packaging is wasteful
- Packaging should act as stowage and comprise an architectural element
  - Packaging which acts as storage eliminates the need for storage-related hardware
  - Packaging applied as furniture may reduce the need for habitat furnishings

Edible Packaging Concepts

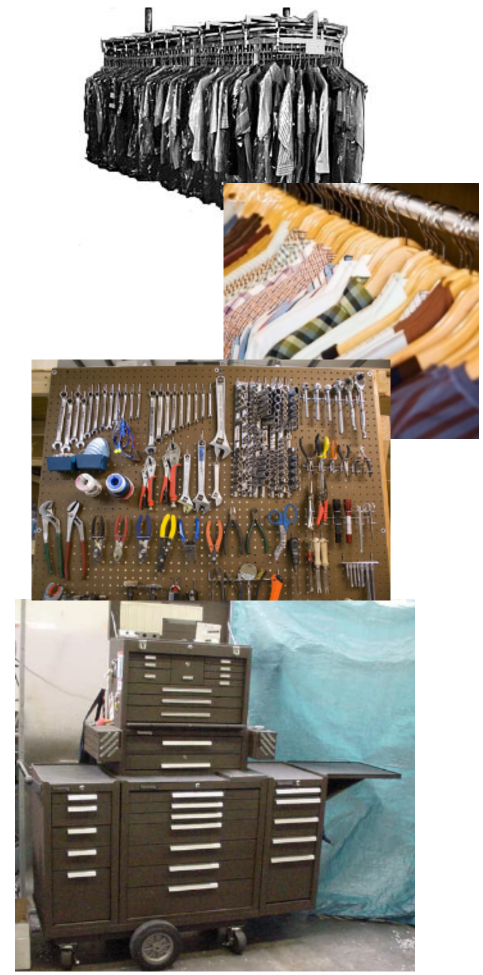
- Potential Applications
  - Void fillers
  - Corner protection
  - Environmental sealing
  - Load distribution
  - containment
- Conclusions
  - Edible substances may viably be useful as packaging
  - Their properties for such applications are unsubstantiated
  - Combinations of edible and non-edible packaging may be preferred
- Recommendations
  - Additional study should determine the properties and potential applications for these and other candidates
  - Further study may identify opportunities to develop improved candidates

Candidates*

- Edible Paper
- Edible Ink
- Edible films
- Popcorn
- Rice cakes
- Beans and Lentils
- Edible Fabric
- Semi-consumable materials
  - Variably filled bubble-wrap
- Potato flakes
- Sausage
- Wax-coated cheese
- Newly Engineered Foods

1/6 G as a Contributor to Packaging Optimization

- Lunar-g offers design opportunities not applicable in 0-g
  - 3-axis restraint is not required in the lunar operating environment
  - Soft structures can hang rather than “float”
  - Static (habitat) and dynamic (rover) environments present unique challenges and opportunities (reduced gravity, undiminished mass)
  - Pockets, hangers, pegboards, hooks, drawers, bins, hoppers, shelves:
    - All depend on the presence of gravity.
    - All represent viable options for Cx packaging/deployment/storage
- Conclusions
  - NASA’s history in LEO programs and missions predisposes the community toward familiar packaging paradigms which disregard gravity
  - Mass and volume associated with 0-g operability may be shed for Cx applications
  - Gravity-enabled solutions generally have implications for the elements within which the packages are transported and utilized
- Recommendations
  - The potential to advantageously apply gravity should be assessed in all Cx packaging and storage applications. It’s light weight, low volume, readily available, and very reliable



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Polyethylene as a Packaging Material

- Potential advantages associated with PE used as packaging
  - Material properties and processing versatility may favor in-situ recycling
    - Rapid prototyping
  - PE is inexpensive, durable, flexible, abrasion resistant, puncture resistant, a good radiation barrier
    - Potential material for in-situ-fabricated internal secondary structures
  - Manufacturing technology and formulations are very well established
- Recommendation
  - Materials and processes experts, operations planners, design engineers, and crewmembers should collectively brainstorm the potential uses for Polyethylene in lunar exploration systems and missions with the intent of identifying high-leverage concepts for the versatile application of this material to achieve initial and residual value.
  - In so doing, other materials may be identified which also offer similar opportunities and versatility

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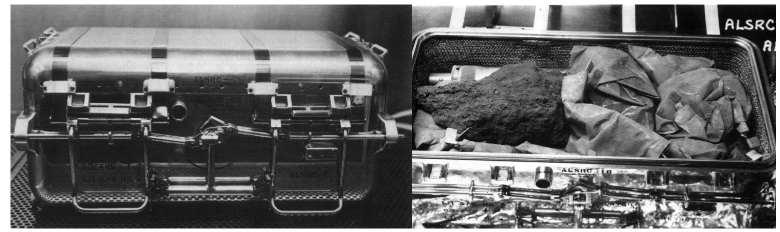
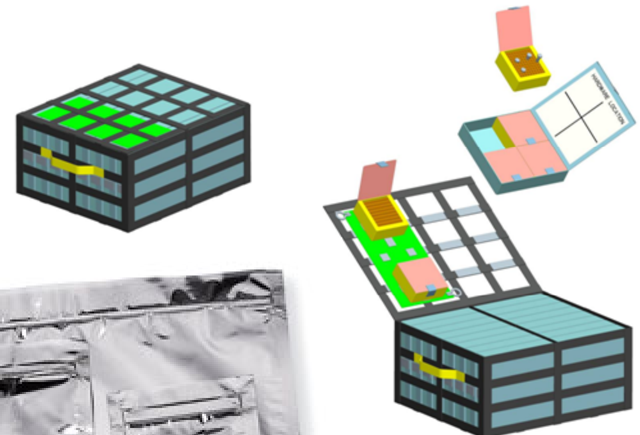
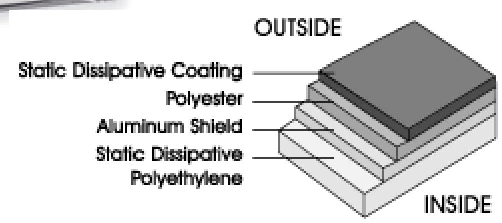
Sample Return Packaging - revisited

- The interim review reported one concept (SRP used as delivery container for Lunar Science Tools), while another was in process
- High related costs and trans-element operability increase the value of efficiency in this application
- Revisited concept involves :
  - use of low-mass containment bags for sample containment
  - Automated tracking of container usage relative to time and location at which sample was collected
- Conclusions
  - Compatible accommodations must be established aboard Altair and Orion
  - Compatibility with SPR and EVA suits is critical
- Recommendations
  - Share these results with groups developing Altair, Orion, EVA suits, and sample recovery plan to emphasize the importance of optimization in the context of the Cx architecture







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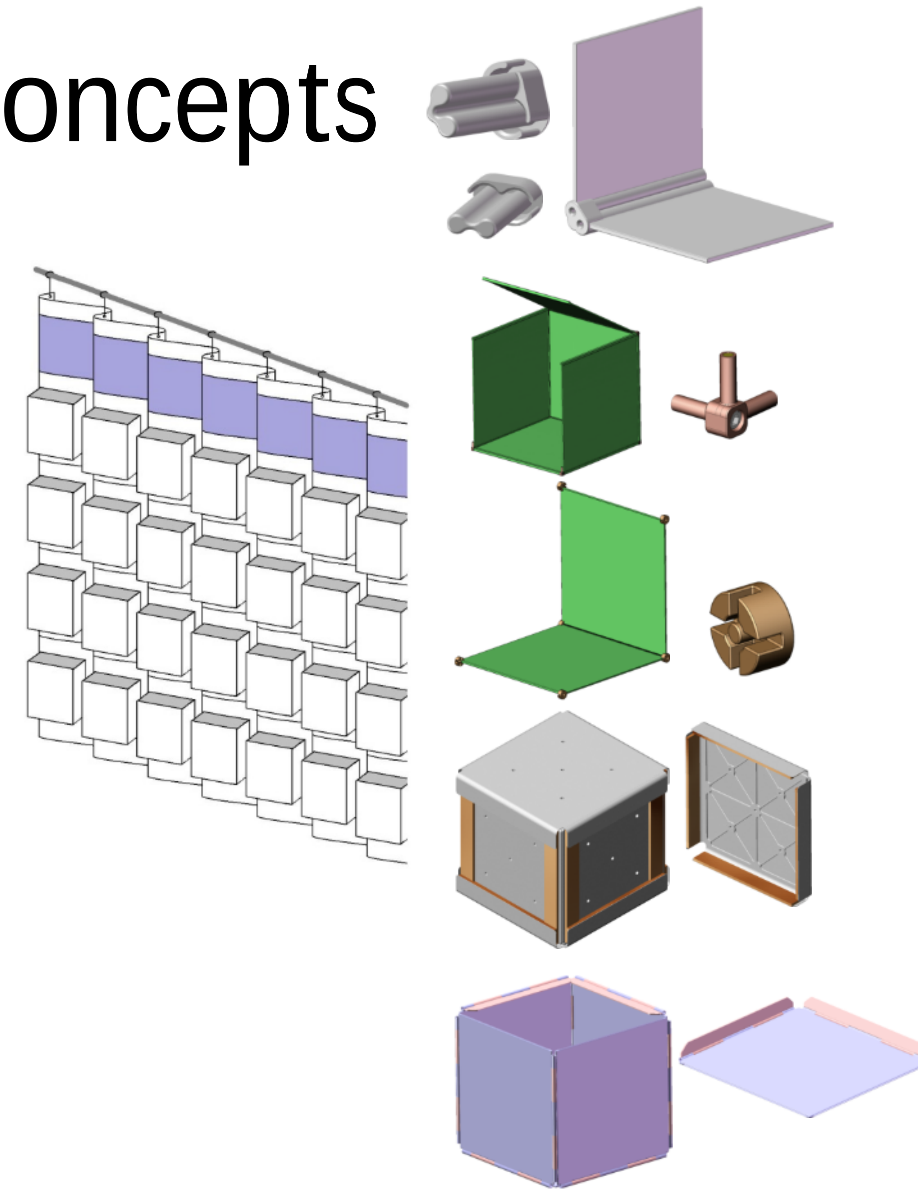
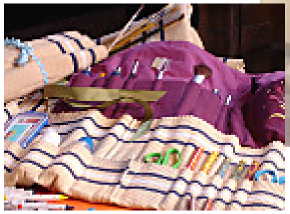
Design Concepts

- Soft concepts: Stowage “Curtains”
- Modular rigid container Concepts



Stowage Curtain Concept



- This concept was inspired by:
  - Terrestrial analogs
  - Phase-weighted performance philosophy (described later)
  - Desire to provide packaging, stowage, and operational deployment all using one hardware element
  - Desire to develop an adaptive packaging scheme which maintains a common and simple set of interfaces to the accommodating element while being amenable to custom-configured interfaces to contents

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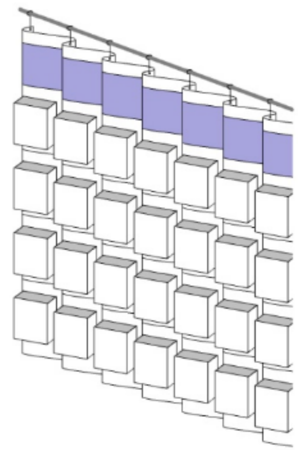
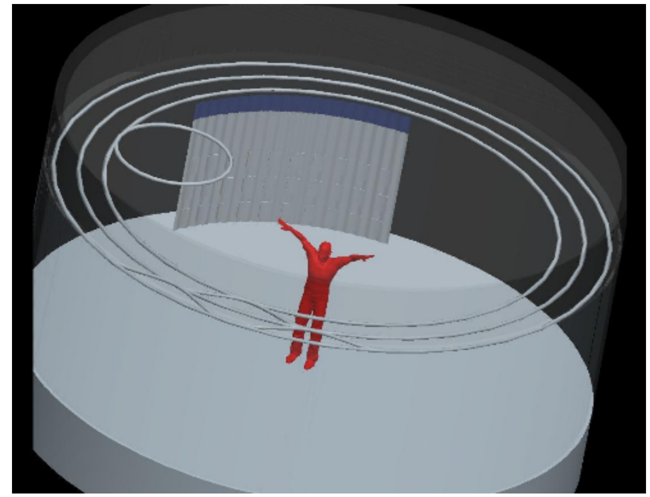
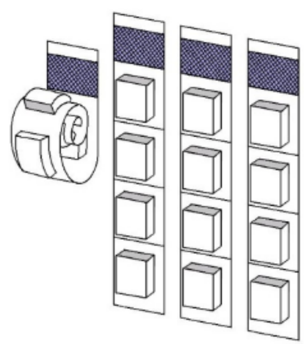
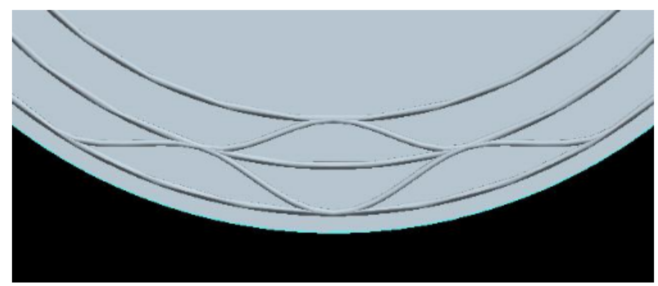
Stowage Curtain Concept (cont.)

- Rolled curtain contain and protect contents during delivery phase
- Delivery uses deck as support structure
- Curtains are deployed by crew to track array on ceiling
- Stowage and habitat outfitting concepts are highly co-dependent
- Concept favors an “open deck” habitat interior design approach









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Stowage Curtain Concept (cont.)

- Other optimization opportunities include:
  - Using engineered fabrics to provide application-supportive performance
  - Using evacuation of trapped to reduce the volume or influence the resiliency of contents as required for effective cushioning of other contents
  - Use of tracks and deck interfaces to host other deployable habitat enhancements
    - Deployable/stowable workstations, showers, medical exam room, etc.

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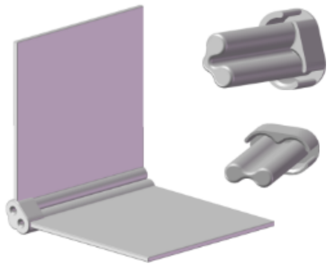
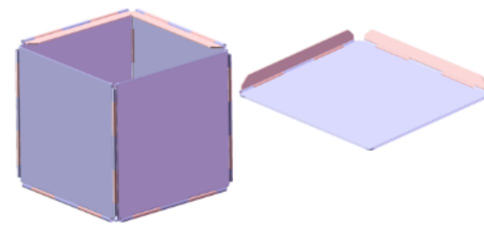
Modular Rigid Panel Concepts

- Several concepts were explored to assess:
  - commonality potential
  - Relative simplicity
- Support investigation of supplemental value potential for modular panels
- Support investigation of implications for packaging accommodations

Modular Rigid Container Concepts

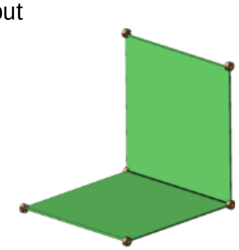


- DOGBONE CONCEPT
  - Differing panels
  - Alternate attach method for side panels
  - Dog bone cross section rod joins two panels
    - Full length engagement or multiple locations along length

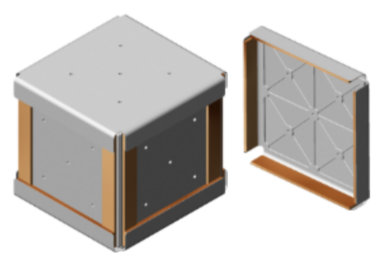


- HINGED PANEL CONCEPT
  - Common panels
  - Slide and lock style locking mechanism (not shown)

- PIP PIN CORNER CONCEPT
  - Common panels
  - Pip pin style locking mechanism
  - Multiple corner designs needed based on final layout



- TINKER TOY CONCEPT
  - Differing panels
  - Alternate attach method for side panels
  - Center screw (not shown) provides locking
    - Latching dogs
    - Compressed rubber
  - Alternate corner piece for non-rectilinear configurations



- LIVING HINGE CONCEPT
  - Top and bottom panels with Living Hinge
  - Flat side panels with Dual-Lock™ fastening
  - Injection molded polyethylene panels with integrated iso-grid
- FABRIC HINGE CONCEPT
  - All panels identical with Dual-Lock™ fastening
  - Fabric hinges with Dual-Lock™ fastening
  - Injection molded polyethylene panels with integrated iso-grid

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Rigid Panels Concepts: Implications

PROS

- Panels may be adapted by crew to create habitat furnishings
- Potential use of panels as radiation shielding
- Potential to create “hybrid” packaging using fabric and rigid components
- Possible concept applicability to unpressurized packaging applications
  - Provide assured containment

CONS

- Packaging interfaces to contents and encompassing environments introduce potential for inefficiency
  - Increased local loading conditions at rigid interfaces
  - Void areas within and surrounding containers
- “One-size-fits-all” approach further threatens efficiency
- Application of rigid enclosures should be the exception rather than the rule
  - Requirements must dictate the need
  - Otherwise use soft-packaging

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OSS believes that optimized packaging will address a “phased requirements compliance” philosophy

- Objectives:
  - develop packaging which satisfies functional and performance requirements for specific mission phases
  - Identify implications for improving the design and/or performance of accommodating elements
- Intended advantages:
  - Minimize down-stream penalties once each mission phase has been endured
  - Endure mission phases with adequate margins only in the configurations applied during said phases
  - Optimize the prioritization of metrics on a phase-by-phase basis and seek the optimal balance of performance

Understanding the packaging-influencing distinctions between STS/ISS and Cx applications provides a point of departure for defining a “phased-compliance” packaging philosophy

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Distinctions between STS/ISS Packaging and Cx Packaging

- STS/ISS packaging serves a distinctly different architecture and mission model than Cx
  - Reusable packaging may be applied for multiple missions
  - Bi-directional transport is less constrained (at least until STS retirement)
  - Multi-axis restraint and containment are constant requirements
- The generic solutions applied for STS/ISS offer insufficient efficiency optimization potential for Cx applications
- Lunar settings present distinct challenges and opportunities as compared to LEO settings
  - End-user Cx packaging functions occur in a gravity environment
  - Once delivered to the moon, this stuff is NEVER* coming back

*Nothing will return from the moon unless the value of its return to Earth exceeds the cost of its return

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Phased Requirements Compliance Concepts

Mission Phase	Preferred Packaging Attributes	Design Implications
Packaging Design Engineering	Capability to accommodate all transportable equipment Ability to apply reliable materials and processes to design and create packaging	Cx package designs will reflect greater point-design optimization to achieve the required levels of efficiency. Design themes and philosophies will be optimized in place of a generic standard packaging approach
Pre-launch Processing	Ability to manage packaging in 1-G Ability to adapt packaging to accommodate unexpected delivery requirements	A versatile packaging scheme wherein point-design packages behave compatibly with hosting vehicles

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Phased Requirements Compliance Concepts

Mission Phase	Preferred Packaging Attributes	Design Implications
Installation to Lunar-destined Cx Elements	Packaging integrates to elements with minimal mass and volume "overhead"	Eliminate secondary structures which offer little or no value through the most extended mission phases (minimize down-stream penalties)
Launch	Package, contents, and hosting element must endure launch environments. Mass properties favor a controllable and high-performance integrated vehicle	Promote short and robust load paths. Reduce non-contents-related mass. Promote small MOI. Present favorable dynamic characteristics of contents, packaging, and hosting vehicle.
Trans-lunar	Endure low-intensity loiter environments. Endure pressure cycling contingencies	

Phased Requirements Compliance Concepts

Mission Phase	Preferred Packaging Attributes	Design Implications
Lunar descent	Promote Descent Stage controllability.	Favor designs which contribute minimal mass and favorable MOI
Lunar landing	Withstand landing loads	Probably encompassed by ability to endure Earth-ascent. Ensure no compromise due to exposure to in-transit contingencies.
In Situ Utilization by Crew	Favor rapid deployment. Maintain inventory control. Minimize crew time spent addressing packaging functions. Create a safe and productive environment. Promote maximum utility from limited habitable volume.	Avoid relocation of contents> Deliver stuff in the packaging within which it will be operationally stored and from which it will deploy and return. Avoid permanent habitat installations dedicated to storage. Consider an “open deck” multi-purpose/adaptive interior

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Phased Requirements Compliance Concepts

Mission Phase	Preferred Packaging Attributes	Design Implications
Packaging contents depleted	Minimize residual materials. Promote on going value of packaging materials. Promote creative adaptations	•Select materials with high degree of in-situ reprocessing potential •Provide usage environment within which residual value is attainable •Enable reduction of packaging volume as contents are depleted
“Spent” packaging: end of service life	•Realize all potential value prior to unrecoverable or material-degrading “disposal” •Minimize physical and operational intrusiveness of waste	Recognize that repeated resupply may take advantage of previously used storage functions. Consider resupply packaging which disregards storage functionality in favor of reduced mass and volume

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Conclusions

- Mass and volume reduction for packaging are but two objectives: OPTIMIZATION at a higher level is the "grail"
- No single packaging design will efficiently meet every application
- Point-design solutions based on a universally effective packaging paradigm will benefit reduction in mass, volume, and residual packaging
- By combining all of these concepts and more in an appropriate manner, significant improvements may be achieved vs. ISS/STS packaging, with concurrent improvement in overall value and functionality

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Take-away Messages

- Optimal packaging influences every aspect of the Cx architecture, not just the containment of portable supplies
- The packaging concept must be coordinated with the element design and operational concepts to ensure mutual compatibility and mutual net benefit
- A Packaging Working Group would be instrumental in defining, mandating, and monitoring/advocating adherence to a universally applicable/beneficial packaging paradigm of the Cx architecture
- Unpressurized packaging is as much a challenge as pressurized packaging, and demands additional dedicated study to ensure mutually optimal performance across the Cx architecture